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Make or Buy: An Analysis of the Impacts of 3D Printing Operations, 3D Laser Scanning Technology, and Collaborative Product Life-Cycle Management on Ship Maintenance and Modernization Cost Savings

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A team from the Naval Postgraduate School conducted a trade-off analysis of in-sourcing (i.e., make) versus outsourcing (i.e., buy) the production of legacy parts for ship maintenance and modernization with a focus on cost savings given the need for cost-effective sustainment. The purpose of the study was to compare the make/buy trade-off for a comparison of implementing 3DLST, 3DP, and CPLM for U.S. Navy fleet maintenance and upgrading. Cost estimates for in-sourcing and outsourcing were developed as well as the impact of insourcing part production cycle time reduction on fleet readiness assessed. The results have several significant implications for fleet maintenance and modernization practice. The results indicated that there would be significant potential savings with in-sourcing, suggesting that the combination of the three technologies have created a potential shift in the optimal acquisition modes for fleet parts.

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Make or Buy: An Analysis of the Impacts of 3D Printing Operations, 3D Laser Scanning Technology, and Collaborative Product Life-Cycle Management on Ship Maintenance and Modernization Cost Savings

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Abstract

A team from the Naval Postgraduate School conducted a trade-off analysis of in-sourcing (i.e., make) versus outsourcing (i.e., buy) the production of legacy parts for ship maintenance and modernization with a focus on cost savings given the need for cost-effective sustainment. The purpose of the study was to compare the make/buy trade-off for a comparison of implementing 3DLST, 3DP, and CPLM for U.S. Navy fleet maintenance and upgrading. Cost estimates for in-sourcing and outsourcing were developed as well as the impact of in-sourcing part production cycle time reduction on fleet readiness assessed. The results have several significant implications for fleet maintenance and modernization practice. The results indicated that there would be significant potential savings with in-sourcing, suggesting that the combination of the three technologies have created a potential shift in the optimal acquisition modes for fleet parts.

Introduction

Ship maintenance and modernization—repairs and improvements to the existing fleet—are central to U.S. naval operations. The current cost-constrained environment within the federal government and the U.S. Department of Defense (DoD), as well as evolving threats, require naval leadership to maintain and modernize the fleet to retain technological superiority while simultaneously balancing budget cost constraints and extensive operational commitments. Maintenance programs play a critical role in meeting these Navy objectives.

New technologies can facilitate meeting fleet readiness requirements within current cost constraints, but only if those technologies are adopted and applied effectively and efficiently on a wide scale. One of the most important issues concerns what work to in-source within Navy organizations and what work to outsource, that is, the “make versus buy” decision. Both in-sourcing and outsourcing have been promoted as cost-savings tools. Currently, the research on the impact of new technology adoption on the make/buy decision is unclear.

DoD cost-reduction imperatives have forced a review of ship maintenance and modernization tools and methods. The review has found that a particularly acute problem is how to acquire one-off (especially legacy) parts. In ship maintenance, often the parts required were originally manufactured by now-defunct businesses. Often only one, or a few copies, of a given part is required for ship maintenance. Another challenge is the duration and cost of the traditional acquisition process when applied to parts, especially when legacy, unique, or few parts are needed. When outsourced, fabricating parts involves an extensive acquisition process in addition to reverse engineering and manufacturing legacy replacement parts. Acquiring a few parts of a given kind from organizations that are not the original equipment manufacturer (OEM), a local vendor, and sometimes even from the OEM, tends to take longer and cost more than acquiring the lower per unit costs for making many copies of a currently manufactured part. Manufacturing small numbers of parts such as customized or obsolete components can be very expensive. The loss of the small- and medium-size industrial base to support ship maintenance and upgrades leads to very expensive manufacturing of custom parts. In the current manufacturing base, custom parts are very expensive to design and produce in job shops using traditional methods. Also, engineering design changes balloon the costs of projects by creating large numbers of customized parts or modifications of existing parts.

Problem Description

In a 2013 report on U.S. Air Force sourcing titled *Enabling Early Sustainment Decisions, Application to F-35 Depot-Level Maintenance*, Drew, McGarvey, and Buryk (2013) of the RAND Corporation proposed and applied a method for recommending sourcing with two dimensions: frequency of need and asset specificity (Figure 1). In this framework, “OEM” (upper left in Figure 1) is outsourcing to the original equipment manufacturer, “Organic” (upper right in Figure 1) is in-sourcing by the U.S. military, “Spot-market contract” (lower left in Figure 1) is outsourcing for one or a few of a single part type, and “Longer-term contract” (lower right in Figure 1) is long-term outsourcing to (often) a different private manufacturer for many parts.

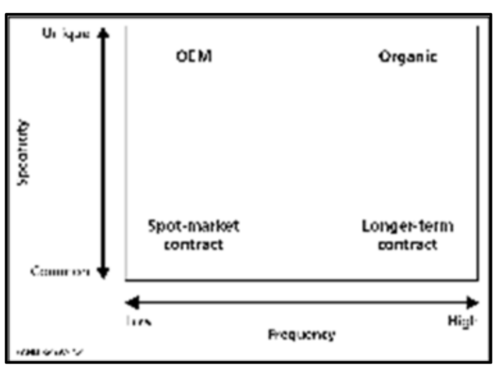

Figure 1. A Conceptual Sourcing Framework
(Drew et al., 2013)

The RAND study says, in part,

> a unique activity that occurs frequently would be something that the Air Force would want to perform with organic assets [i.e., in-source]. That is to say, if an activity is unique and the organization requires it frequently, no external provider could capture a greater economy of scale than the Air Force (due to its uniqueness), and performing it in-house should yield a higher return on investment (due to high frequency). However, as that frequency declines and if the activity remains unique, it may be difficult for the Air Force to capture any return on investment for capital setup costs. (Drew et al., p. 9)

The kinds of parts replacement studied in the current work are primarily unique and few in frequency. The Air Force sourcing solution is to use spot-market contracts (i.e., buy from any qualified supplier) if the part is relatively simple or to outsource to the OEM if the part is complex.

3DLST and 3DP have the potential to generate large cost savings by in-sourcing production of either type of part. However, it is not clear whether the Navy will capture the potential savings if the three technologies are used by private industry. More savings may accrue if the technologies are put to use by Navy organizations. However, building these internal capabilities, a skilled workforce, and the added capacity for this activity will require a substantial initial investment. A cost comparison of outsourcing versus in-sourcing fleet maintenance and upgrading operations with these three technologies can provide insight for deciding whether the investment provides an acceptable return. A critical implementation issue is whether to develop 3DLST, 3DP, and CPLM capabilities within the service (i.e., in-sourcing) or to have industry make the part (i.e., outsourcing).

The current study addresses these important issues by attempting to answer the following questions:

1. What are the relative costs of in-sourcing 3DLST, 3DP, and CPLM fleet maintenance and modernization compared to outsourcing those same operations with contractors?
2. What cost savings may be captured by the use of 3DLST, 3DP, and CPLM for fleet maintenance and modernization if those operations are insourced?

Background

The Congressional Research Service defines outsourcing as a decision by the government to purchase goods and services from sources outside the affected government agency. DoD officials report that “in-sourcing has been, and continues to be, a very effective tool for the Department to rebalance the workforce, realign inherently governmental and other critical work to government performance, and in many instances to generate resource efficiencies” (GAO, 2012, p. 14). Beyond workforce realignment, in-sourcing offers additional advantages of cost savings and improved cycle time efficiencies. Table 1 identifies advantages and disadvantages to outsourcing for the DoD.

Table 1. Advantages and Disadvantages of Outsourcing for DoD
(Marquis, 2011, p. 9)

Advantages of Outsourcing	Disadvantages of Outsourcing
Allows DoD to focus on core competencies	Contractors traditionally provided too little documentation/lessons learned/knowledge transfer in past
Private industry competition increases efficiency and decreases costs	When contracts end, often so does the product specific knowledge and maintenance can be costly
Paradigm shift to insourcing will be organizationally expensive	Can lead to loss or atrophy of DoD organic employee technical skill set
Private industry covers the cost of continuous IT training; free to DoD	Perceived loss of control of effort
Allows for flexibility in personnel ramp-ups and downs resulting in cost savings for project and long-term workforce	Accountability: contractors are accountable to their companies, not the DoD or the effort
Usually lower cost alternative	IT efforts appear pricey at first glance!
Access to economies of scale	Many IT efforts have been mismanaged, leading critics to question outsourcing as fault
Access to private industry allows for partnership on innovation and use of proven, best business practices	When over-performed, can deplete the DoD organic workforce talent
Lowers DoD's fixed costs	The timing of insourcing effort coincides with large workforce retirement-hiring - needs could be much more than expected
Industry can retain talent better with better job category and salary structures for IT jobs	Acquisition issues: DoD cannot pick the precise people to work effort - success is about having the right people work the effort at the right time
Private industry already has the people on-board.	Success requires strong leadership and well-defined requirements, which are often hard to obtain
Have requisite talent & experience to deploy solution faster	Can be risky when not poorly contracted and managed
Helps private industry and the U.S. economy	

Additive Manufacturing (3DP), CPLM, and 3DLST Technologies

Additive Manufacturing

Additive manufacturing (AM) is often equated to 3DP. For the purposes of the current study, the two labels are used interchangably in spite of minor differences in meaning. Additive manufacturing is defined by the American National Standards Institute as the "process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing and freeform fabrication" (Wohlers, 2013). Additive manufacturing is a relatively new technology that directly deposits materials to make products by sequentially laying down millions of particles in thousands of layers to build up the final component. Three-dimensional design documents (e.g., from use of 3DLST) direct manufacturing hardware. By controlling the movement of the material deposition equipment and the flow of material, the process controls where particles are deposited in each layer, thereby creating surfaces, shapes, and cavities. Materials can be plastic for fast prototyping, metals, ceramics, or human tissue. 3DP has several advantages over traditional manufacturing methods. First, a primary advantage is the ability to create almost any product shape, with the only limitation being the need for each layer of material to have a layer below it for support, although secondary materials can be used to provide support under overhanging component parts during manufacturing. Second, whereas traditional methods are subtractive (e.g., using traditional methods with lathes), the AM process is additive, greatly reducing waste materials.

Collaborative Product Life-Cycle Management

Product life-cycle management addresses the issues related to a product throughout its life. Collaborative product life-cycle management (CPLM) works to integrate product life-cycle management across project participants, time, and technologies. CPLM technology provides a common platform to electronically integrate other technologies, such as 3DLST images and manufacturing files for additive manufacturing, to enable collaboration among all parties involved in a given project across project phases and regardless of their geographic location (e.g., on a ship at sea and at a land-based depot). CPLM tools also provide a means to store the images and all related maintenance work within a common database accessible by all participants in a ship alteration or modernization project. CPLM is defined by CIMdata as a strategic business approach applying a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, from concept to end of life (CIMdata, 2007). It integrates people, processes, and information.

Specific CPLM tools include technologies that support data exchange, portfolio management, digital manufacturing, enterprise application integration, and workflow automation. A range of industries has invested in CPLM solutions, including those involved in aerospace and defense, automotive and transportation, utilities, process manufacturing, and high-tech development and manufacturing. The CPLM market is poised for further growth with vendors expanding product offerings as the industry evolves.[1]

3DLST

3DLST scanners create a three-dimentional “point cloud“ of the surface of an object. Similar to cameras in some ways, they have a cone-shaped field of view, but can also collect distance information about each point, allowing each point to be located in a three-dimensional space. Usually, multiple scans are required from different directions to capture adequate information to create a description of the object. Most manufacturers’ scanners work by scanning a target space with a laser light mounted on a highly articulating mount, enabling data capture in virtually any orientation with minimal operator input. Some also incorporate a digital camera that simultaneously captures a 360° field-of-view color photo image of the target. Once the capture phase is complete, the system automatically executes proprietary point-processing algorithms to process the captured image. The system can generate an accurate digital 3D model of the target space; automatically fuse image texture onto 3D model geometry; export file formats ready for commercial, high-end design; and import them into 2D/3D computer-aided design (CAD) packages.

Terrestrial laser scanning technology is well established as a valuable tool in practice and is currently used in a variety of industries. According to industry analysts, laser scanner manufacturers and related software and service providers report strong activity across many markets, including shipbuilding, offshore construction and repair, onshore oil and gas, fossil

[1] The two largest U.S. shipyards that construct aircraft carriers and submarines are also transitioning into CPLM solutions. Typically, CPLM vendors do not focus efforts on the shipbuilding industry because of its size relative to other products, such as automotive or aerospace. Having a CPLM tool designed specifically for an industry has a significant impact on the tool’s efficiency within that industry.

and nuclear power, civil and transportation infrastructure, building, automotive and construction equipment, manufacturing, and forensics (Greaves & Jenkins, 2007).

Research Approaches and Methods

The current research developed estimates of the impacts of the three technologies (3DLST, 3DP, and CPLM) on fleet maintenance costs by comparing the costs of different make/buy strategies. The background, issues, and cost estimates were then used in the integrated risk management approach that includes a real options analysis.

To estimate the make/buy strategy costs, the traditional investment analysis approach was reverse-engineered using the following steps:

- Describe the make/buy strategies.
- Estimate revenues that reflect benefits using a market-comparable approach.
- Estimate a return on investment (ROI) for each strategy using Knowledge Value Added models.
- Estimate costs of each make/buy strategy using the ROI estimates and estimates of benefits.
- Estimate potential cost savings by comparing costs of make/buy strategies.

The Knowledge Value Added (KVA) modeling methodology is central to estimating the make/buy strategy costs. KVA measures the value provided by human capital and IT assets by an organization, process, or function at the subprocess level. It monetizes the outputs of all resources, including intangible knowledge assets. Capturing the value embedded in an organization's core processes, employees, and IT enables calculation of the actual cost and revenue of a product or service.

Total value is captured in two key metrics: return on investment (ROI) and return on knowledge (ROK). Although ROI is the traditional financial ratio, ROK identifies how a specific process converts existing knowledge into producing outputs so decision-makers can quantify costs and measure value derived from investments in human capital and IT assets. A higher ROK signifies better utilization of assets. If technology investments do not improve the ROK value of a given process, steps must be taken to improve that process's function and performance.

The goal is to determine which core processes provide the highest ROIs and ROKs, and to make suggested process improvements based on the results. In the current work, KVA is used to measure the benefits of adopting the three technologies for ship maintenance. This analysis provides a means to check the reliability of prior studies' estimates of the potential ROI core process improvements from using CPLM, AM (3DP), and 3DLST in ship-maintenance core processes in the U.S. Navy yards.

Integrated Risk Management and Strategic Real Options Analysis

Integrated Risk Management (IRM) is an eight-step, quantitative software-based modeling approach for the objective quantification of risk (cost, schedule, technical performance), flexibility, strategy, and decision analysis. The method can be applied to program management, resource portfolio allocation, return on investment to the military (maximizing expected military value and objective value quantification of nonrevenue government projects), analysis of alternatives or strategic flexibility options, capability analysis, prediction modeling, and general decision analytics. The method and tool set provide the ability to consider hundreds of alternatives with budget, performance, and

schedule uncertainty, and provide ways to help the decision-maker maximize capability and readiness at the lowest cost.

In this study, IRM provides a way to differentiate among various alternatives for implementation of 3DLST, CPLM, and 3DP with respect to ship maintenance processes, and to postulate where the greatest benefit could be achieved for the available investment from within the portfolio of alternatives. As a strategy is formed and a plan developed for its implementation, the toolset provides for inclusion of important risk factors and allows for continuous updating and evaluation by the program manager.

Cost Saving Estimates

Several challenges arise in expanding previous research on Navy investment strategies in new technologies to investigate make/buy strategies. One challenge is that previous research was often based on a specific portion of the parts used in Naval ship maintenance (e.g., high-, medium-, or low-complexity parts). These product types differ in their costs and market comparable values, and therefore, in their contributions to fleet readiness. Make/buy analysis should consider the potential for in-sourcing all three types of parts. A second challenge is differentiating costs generated by industry from costs generated by parts production within the Navy. These costs differ due primarily to differences in labor costs. A third challenge is the description of the make/buy strategies.

Describing Make/Buy Strategies

Estimates of annual production rates are based on data collected for one depot that manufactures approximately 27,000 parts per year, of which 25% were high complexity, 50% were medium complexity, and 25% were low complexity (Mackley, 2014). Table 2 shows the estimated industry and Navy production rates for five make/buy strategies ranging from all-buy (100% by industry) to all-make (100% by Navy). These estimates assume that the Navy would produce highly complex parts first (in the lowest "make" strategy), then add medium-complexity parts as it increased the fraction of parts made, and produce low-complexity parts only in strategies that have the Navy making all the parts (in the highest "make" strategy).

Table 2. Annual Production Rate Estimates of Five Make/Buy Strategies

	Part Complexity (% of total parts)	High (25%)		Medium (50%)		Low (25%)		Parts Produced by Industry	Parts Produced by Navy	Total Parts Produced
	Part Manufacturer	Industry	Navy	Industry	Navy	Industry	Navy			
% Made by Navy	0	6,750	0	13,500	0	6,750	0	27,000	0	27,000
	25	0	6,750	13,500	0	6,750	0	20,250	6,750	27,000
	50	0	6,750	6,750	6,750	6,750	0	13,500	13,500	27,000
	75	0	6,750	0	13,500	6,750	0	6,750	20,250	27,000
	100	0	6,750	0	13,500	0	6,750	0	27,000	27,000

The production rates reflect two extreme strategies and three shared-production strategies. The first strategy (0% Navy production) is the extreme strategy in which all parts are made by industry. This strategy is relatively close to the current conditions in which most parts production is outsourced to industry. The second strategy (25% Navy production) reflects the Navy's producing all complex parts and outsourcing all medium-complexity and low-complexity (aka "simple") parts to industry. The third strategy (50% Navy production) reflects the Navy's producing all high-complexity parts and half of the medium-complexity parts, while outsourcing half of the medium complexity parts and all simple parts to industry. The fourth strategy (75% Navy production) reflects the Navy producing all high- and

medium-complexity parts and outsourcing all simple parts. The last strategy (100% Navy production) is the extreme strategy in which all parts are made by the Navy.

As shown in Table 2, the “Parts Produced by Industry” and “Parts Produced by Navy” columns, the Navy increases production as the make/buy strategies shift from low percentage made by the Navy to higher percentages made. The “Total Parts Produced” column shows that these strategies reflect shifts in production between industry and the Navy, not changes in the total number of parts produced.

Estimating Revenues That Reflect Benefits

Benefits were estimated by multiplying the production rates in Table 2 by the average part values. The conservative $6,000 average value of a complex part is supported by an interview of an expert by one of the NPS research team. That expert said, “Externally we see charges anywhere between $6,000 to $8,000 dollars and upwards of $15,000 per model” and later confirmed that $12,000 was “at the upper end of your range” (personal interview summarized in Kenney, 2013). The modelers assumed that medium-complexity parts had an average value of $3,000 each and that low-complexity parts had an average value of $1,000 each. Table 3 shows the estimated values of produced parts for each make/buy strategy.

Table 3. Estimated Annual Benefits of Five Make/Buy Strategies

	Complexity (% of total	High (25%)		Medium (50%)		Low (25%)		Parts Value Produced by Industry ($1,000/yr)	Parts Value Produced by Navy ($1,000/yr)	Total Parts Value ($1,000/yr)
	Part Manufacturer	Industry	Navy	Industry	Navy	Industry	Navy			
	Avg. Part Value ($1,000/part)	6	6	3	3	1	1			
% Made by Navy	0	$40,500	$0	$40,500	$0	$6,750	$0	$87,750	$0	$87,750
	25	$0	$40,500	$40,500	$0	$6,750	$0	$47,250	$40,500	$87,750
	50	$0	$40,500	$20,250	$20,250	$6,750	$0	$27,000	$60,750	$87,750
	75	$0	$40,500	$0	$40,500	$6,750	$0	$6,750	$81,000	$87,750
	100	$0	$40,500	$0	$40,500	$0	$6,750	$0	$87,750	$87,750

Note. Benefits are estimated in thousands of dollars per year.

Estimating Returns on Investment

Estimated Returns on Investment (ROI) were generated with KVA models. Each KVA model reflected the appropriate average 2013 labor costs (Navy) based on work by Mackley (2014) and market value of the common unit of output (high-, medium-, or low-complexity parts). The estimated Returns on Investment are shown in Table 4.

Table 4. Estimated Returns on Investment (ROI) of Five Make/Buy Strategies

	Part Complexity (% of total parts)	High (25%)		Medium (50%)		Low (25%)	
	Part Manufacturer	Industry	Navy	Industry	Navy	Industry	Navy
% Made by Navy	0	573%	NA	151%	NA	12%	NA
	25	NA	1120%	151%	NA	12%	NA
	50	NA	1120%	236%	510%	12%	NA
	75	NA	1120%	NA	358%	12%	NA
	100	NA	1120%	NA	358%	NA	103%

The relatively large returns in Table 4 are consistent with the savings found by industry.

Estimating Production Costs and Cost Savings

Costs for each make/buy scenario can be estimated using the definition of Return on Investment:

ROI = (Benefits – Costs) / Costs

which can alternatively be written as

Cost = Benefits / (ROI + 1).

The equation above was used with the benefits (Table 3) and Returns on Investment (Table 4) to estimate the costs of each make/buy strategy. The total cost of each make/buy scenario (rows in Table 5) is the sum of six costs: the costs generated by industry to produce high-, medium-, and low-complexity parts plus the costs generated by the Navy to produce high-, medium-, and low-complexity parts. In some strategies some of these costs are zero, such as the Navy cost when 100% of parts are produced by industry, or industry cost when 100% of parts are produced by the Navy. Capturing all six cost components for each strategy assures the inclusion of all relevant production costs.

Table 5. Estimated Annual Costs of Five Make/Buy Strategies

Part Complexity (% of total parts)		High (25%)		Medium (50%)		Low (25%)		Parts Cost by Industry ($1,000/yr)	Parts Cost by Navy ($1,000/yr)	Total Parts Production Cost ($1,000/yr)
	Part Manufacturer	Industry	Navy	Industry	Navy	Industry	Navy			
% Made by Navy	0	$6,022	$0	$16,109	$0	$6,022	$0	$28,152	$0	$28,152
	25	$0	$3,319	$16,109	$0	$6,022	$0	$22,130	$3,319	$25,449
	50	$0	$3,319	$6,022	$3,319	$6,022	$0	$12,043	$6,638	$18,681
	75	$0	$3,319	$0	$8,841	$6,022	$0	$6,022	$12,160	$18,181
	100	$0	$3,319	$0	$8,841	$0	$3,319	$0	$15,479	$15,479

Figure 2 shows these results in graphical form by plotting the costs in the “Parts Cost by Industry,” “Parts Cost by Navy,” and “Total Parts Production Cost” columns of Table 5.

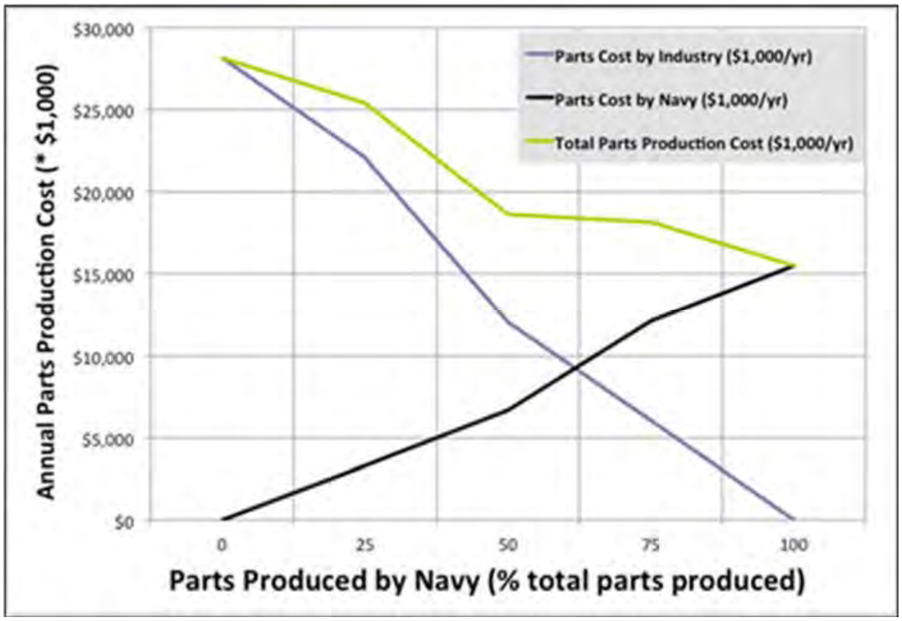

Figure 2. Estimated Annual Costs of Five Make/Buy Strategies

Savings increase with the volume of parts manufactured by the Navy (more in-sourcing). Savings at the depot studied by having the Navy instead of industry produce all parts are estimated to be $12,673,000 ($28,152,000–$15,479,000) per year at the depot investigated. Assuming 10 depots that apply this strategy implies savings that exceed $120 million annually. For context, these estimated savings can be compared to the threshold set by the National Defense Authorization Act for Fiscal Year 2012:

> (e) Determination relating to the conversion [from outsourcing to in-sourcing] of certain functions … in determining whether a function should be converted to performance by Department of Defense civilian employees, the Secretary of Defense shall …
>
> (C) Ensure that the difference in the cost of performing the function by a contractor compared to the cost of performing the function by Department of Defense civilian employees would be equal to or exceed the lesser of …
>
> (I) 10 percent of the personnel-related costs for performance of the function; or
>
> (ii)) $10,000,000

The potential savings forecasted above far exceed the $10 million threshold set by the statute, thereby supporting the adoption and use of these technologies.

Real Options Analysis

Four major strategies were identified and solved using ROV SLS technology as options for the decision-making process concerning planning for further action:

- **Strategy A: Base case.** Keep outsource purchasing vast majority of inventory. This is a risky strategy. Opportunity losses are occurring due to missed financial savings and control over the process in the long run.

- **Strategy B: Outsource.** Buy all 100%: Outsource all manufacturing to outside contractors. This strategy is risky because it leads to dependency on organizations that are outside the control of the Navy.
    - Open Architecture. To reduce the risk of dependency on a few vendors, the Navy could implement an Open Architecture principle that provides interchangeability of critical parts on a ship without any loss of functionality. That gives the Navy the flexibility to choose vendors based on objective parameters (price, frequency, availability).
    - Exit. This strategy is not expensive to abandon. The Navy can easily go to other options without any substantial costs.
- **Strategy C: Insource.** Make all 100%: This is the option to manufacture everything "in-house" immediately. The ROI is high but the cost and risks are very high if it does not work out.
    - Invest 100%. Pros: savings may be captured by the use of 3DLST, 3DP, and CPLM for fleet maintenance and modernization. Cons: additional investment in the technologies costs and risks of immediate in-sourcing.
    - Exit. This option is very costly to abandon because of the high investment costs.
- **Strategy D: Sequential Compound Option**
    - Phase I. 25% PLM: Implement PLM. This is a strategic business approach applying a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise.
    - Phase II. 50%: 3D Laser Scanning Technology. This is a small-scale investment over time with the ability to exit and walk away should the technology not work out as expected. Phasing investments over time hedges any downside risks and reduces any risks of large lump-sum investments.
        - Exit. This technology could still be useful for other options.
    - Phase III. 75%: Additive Manufacturing, 3DP. This includes 3DLST models, conversion to Stereo-lithography STL, Revision of STL Models, AM Machine Setup, and implementation.
        - Exit. 3D technologies could still be applied in other operations of the Navy.
    - Phase IV. 100%: Final Phase. Implement the 3DP, CPLM, 3DLST technologies for all required inventory parts. At this point, the project is too costly to abandon. The Navy will choose to implement the technology limited to the most critical parts of its operations.

To calculate volatility for use in the Real Option Valuation process, Risk Simulator was used. Monte Carlo simulation was applied for estimating Volatility. Figure 3 illustrates six different input assumptions (green cells) with output being estimated as the annual benefit of total production of the parts (yellow cell). The result is shown in Figure 26. The coefficient of variation of 33.61% for the High Risk and 23.62% for the Medium Risk AFCAA settings are the volatilities used in the analyses.

The results (Figure 3) show that Strategy D has the highest value. This Sequential Compound Option involves implementing new technologies in phases, thus giving management the ability to exit at any stage of the project while minimizing the risk of losses.

Strategy Path	Decision	Strategic Value	Notes
Strategy A	25% Navy As-Is	62,300	AS-IS 25%
Strategy B	Buy 100%	59,597	Buy 100%
Strategy C	Make 100%	72,271	Make 100%
Strategy D	Phased	74,149	Stepwise

Phases	Cost	Timing
Phase 1 Cost	3,319	2 Years
Phase 2 Cost	3,319	4 Years
Phase 3 Cost	5,522	6 Years
Phase 4 Cost	3,319	8 Years
Total Costs	15,479	

Figure 3. Real Options Analysis Results (in $ Millions)

Conclusions and Recommendations

The current work investigated the potential of three emerging technologies (3DP, 3DLST, and CPLM) to generate cost saving in U.S. naval ship maintenance and modernization. The challenges posed by fleet maintenance and modernization and an introduction to in-sourcing and its history within the U.S. federal government were described as a context for the work. An extensive introduction to the three technologies was followed by a description of the research approach and methods. Then cost savings using the technologies under different in-sourcing (make/buy) scenarios were estimated. Real options were used to investigate several in-sourcing versus outsourcing alternatives. The results of these analyses are the basis for recommendations for practice.

Potential cost savings due to the adoption and use of the three technologies were estimated to increase as more parts were manufactured by the U.S. Navy (i.e., insourced), with savings of more than $120 million annually if all parts were insourced. In-house manufacture of complex parts was found to generate the largest savings. In combination with other research, this suggests that complex parts for which few copies are needed are the best candidates for initial in-sourcing using the technologies.

Of the four make/buy strategies analyzed, Strategy D of the phased implementation approach has the highest strategic value. This strategy involves implementing new technologies in phases, thus giving management the ability to exit at any stage of the project, while minimizing the risk of losses.

The results have several significant implications for fleet maintenance and modernization practice. The finding of significant potential savings with in-sourcing suggests that the three technologies have created a potential shift in the optimal acquisition modes for fleet parts. Based on the RAND model of in-sourcing and outsourcing acquisition, as the costs of producing few more different types of parts (e.g., simple versus complex and frequent versus rare) drop with the new technologies, the Navy will be able to capture more benefits by in-sourcing more parts. This concept is shown in Figure 4 as a shift from the dashed lines to the solid lines that include a larger portfolio of parts.

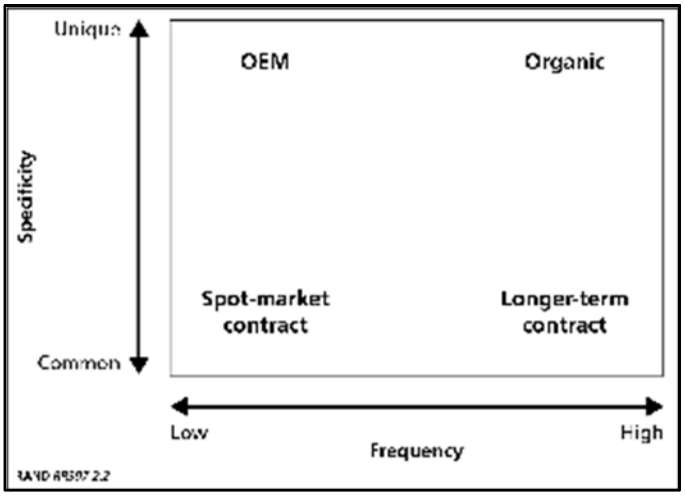

Figure 4. Based on Conceptual Sourcing Framework
(Drew et al., 2013)

Recommendations for the U.S. Navy include the following:

- Adopt the three technologies investigated.
- Test in-sourcing with these technologies starting with low volume complex products.
- Plan to increase the scale of in-sourcing after developing processes and a track record to justify expansion.
- Work to change acquisition regulations and procedures that impede the use of in-sourcing for parts manufacturing.

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